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DEVELOPMENT OF A 100MW S-BAND PULSE KLYSTRON

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Abstract Development of a 100MW S-band pulse klystron is now under way. The design and the result of the first prototype klystron will be presented. The klystron can be operated in the short pulse condition of 100MW output power in 1 μs pulse duration, and in the long pulse condition of 80MW output power in 4 μs pulse duration. Beam voltage for the two conditions are 450kV and 375kV respectively. The output power is extracted from a single output cavity via two pill-box type output windows in parallel. Major parameters of the five integral cavities were optimized by the aid of Field Charge Interaction program(FCI).

INTRODUCTION

Several linear colliding machines aiming at TeV region are now under consideration. National Laboratory for High Energy Physics, KEK, in Japan is proposing a 10 kilometer long electron positron colliding machine named JLC(Japan Linear Collider)[1,2,3,4]. The positron source will be consisted of 10 to 30GeV intense electron linear accelerator powered with 100MW class S-band klystrons. There are some klystrons, such as 150MW klystron[5] or SLAC 5045[6], which output power is exceeding or close to 100MW. However, the klystrons, which are already developed and available in commercial base, are capable of delivering only 35 or 40MW per tube. E3712 is a 100MW output power S-band pulse klystron being developed by TOSHIBA. TABLE I shows the target performance of E3712. E3712 was designed to operate under two conditions. A short pulse operating mode, that is 1μs of RF pulse duration and 100MW of peak output power, and a long pulse operating mode that is of 4μs and 80MW. The two operating modes correspond to the two methods of not using or using a pulse compression technique for driving accelerator cavity. E3712 is expected to be the highest output power pulse klystron, mass-produced by a tube manufacturer.

TABLE I. The target performance of E3712.

Parameters mode	Unit	Value long	short
Output power	(MW)	80	100
Frequency	(MHz)	2856	2856
Beam voltage	(kV)	375	450
Beam current	(A)	460	604
RF pulse duration	(μs)	4.0	1.0
Beam pulse duration	(μs)	6.5	3.5
Repetition rate	(pps)	50	50
Drive power	(W)	300	375
Efficiency	(%)	46	39

ELECTRON GUN

Cathode

Selection of good cathode material is essential to success of high voltage electron gun for pulse klystrons. The cathode of E3712 must be operable at such a high current density of $9A/cm^2$, and must not contaminate the electrode surface with evaporated barium molecules or hydrocarbon, so as to maintain high voltage insulation. To accommodate those conditions, E3712 employes a low operating temperature dispenser cathode with a diameter of 90 millimeters.

Electron Gun Geometry

The dimensions of the electrodes were optimized by electron beam trajectory simulation, along with the computation of the surface electric field distribution. The electric field strength at the surface of the electrodes are maintained less than the practical value that was already proved by other smaller S-band klystrons. The surfaces of the electrodes are mirror-finished to avoid field enhancement. The gun ceramics has a tapered cylindrical dimensions. The diameter of the anode side is larger than that of the cathode side so that field emitted electrons go directly to the positive electrode and do not rush into the ceramics surface.

Suppressing Electron Gun Instability

Resonance inside electron gun housing is a problem. If the electromagnetic field energy is concentrated close to the electron beam and the resonant frequency is in the frequency range where electron beam resistance takes negative value, an oscillation or an instability may occur. The resonant characteristics of E3712 was examined by computing the electromagnetic field in the electron gun including the high voltage oil bath. FIGURE 1 shows the computed resonant characteristics of the gun housing. The highest resistance is less than 5kΩ, that is low enough for stable gun operation.

INTERACTION REGION

The locations and the resonant frequencies of the interaction cavities were optimized by simulating the electron motion with a one dimensional disk

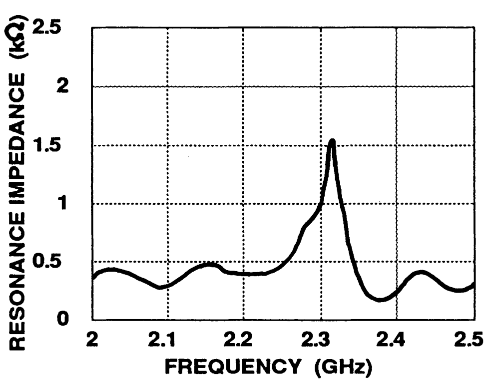

FIGURE 1. Frequency response calculation for E3712 electron gun.

model simulation code[7]. However, the disk model simulation is not so reliable for designing high power pulse klystrons. The beam perveance is so high that the radial electron motion cannot be neglected due to high space charge force. As the drift tube radius is comparatively large, and the gap length is long in order to reduce the electric field strength at the tip of the drift tube, the electric field distribution in the cavity gap is not so uniform that the rigid disk model can be applied. Particle, or ring model simulation can solve the problem, and gives more accurate simulation results. FCI(Field Charge Interaction program)[8] is one of those simulation programs. As three dimensional electron motion is solved completely, the influence of the focusing static magnetic field distribution, that was hardly taken into account by one-dimensional disk model program, can be examined.

Two models of interaction region, consisted of five cavities and of six cavities, were studied with FCI. The gain and the efficiency did not show a great improvement with six cavity model. As the greater the number of cavities, the more complicated instability phenomena may possibly occur, E3712 adopts five integral cavities. FIGURE 2 shows the snap-shot picture of the large signal electron beam motion of E3712, computed with FCI. The trajectory of the electron beam is modulated not only in axial direction but also in radial direction. It can be also figured out that the bunching is different depending on their radius position. As the computation result, it was found that the required drive power for saturation is about 400 watts. 99MW and 140MW output power is possible at the beam voltage of 375kV and 450kV, respectively.

OUTPUT CIRCUIT

Output Cavity and Waveguides

To avoid unexpected instabilities caused by a coupling between output cavity and up-stream-side cavities, the electromagnetic field distribution in output cavity should be as axially symmetric as possible. The electromagnetic field in an output cavity with a single output waveguide iris, as of usual pulse klystrons, may be deflected from the axial direction due to the energy flow from the electron beam to the output waveguide iris. The output cavity of E3712 has two output waveguide coupling irises in the opposite side of the cavity. The electric field inside the output cavity is less deflected because the power flow takes more symmetrical distribution.

Just after leaving the output cavity, the output waveguides are bent

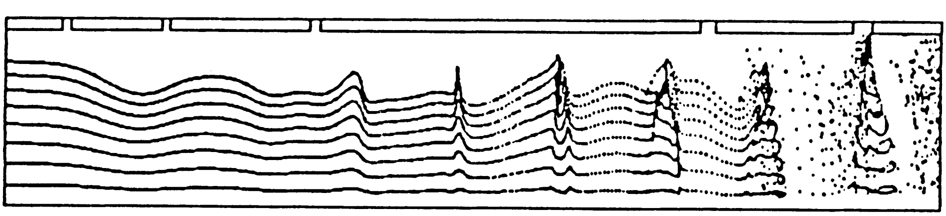

FIGURE 2. Snap-shot view of the beam bunching. A graphic output of FCI.

by E-bends and go upward, and then directed forward by H-corners. Output windows are placed so that the dominant electric field is directed horizontally, and then the output waveguides come to the ends with two rectangular vacuum-tight flanges. The ordinal set-up of E3712 contains an original power combiner that combines the two streams of output power into one waveguide.

Output Window

Output window is the part as delicate as the electron gun. The maximum power capability of S-band output window has not been theoretically investigated. But it may be difficult to apply microwave power exceeding 50MW to a single window when the pulse length is 4µs or longer.

A couple of standard pill-box type window with 99.5% alumina ceramics disk are employed to E3712. The surface of the ceramics disk is coated with TiN(Titanium Nitride)[9], that is a very practical means to suppress multipactoring phenomena. Some windows were tested with a resonant ring up to the peak power of 200MW. FIGURE 3 shows the observed temperature rise of the output window ceramics vs. the resonant ring forward travelling wave power. The figure shows data from three samples with different TiN coating. The output window with a thinnest coating shows sharp temperature rise at 20MW that may be the result from multipactoring. The other sample does not seem to have an abrupt temperature rise at 20MW, but goes hot at higher power. That is resulted from lower resistance of the coating layer. The sample C in FIGURE 3 seems to have no problem. Even at the power of 200MW, the temperature rise is not higher than 3 degree centigrade, that is low enough to assure a reliability of the window, and indicates that the multipactoring phenomena is successfully suppressed. The windows installed to the klystron were coated like the sample C , and then high power tested with the resonant ring to confirm the coating quality.

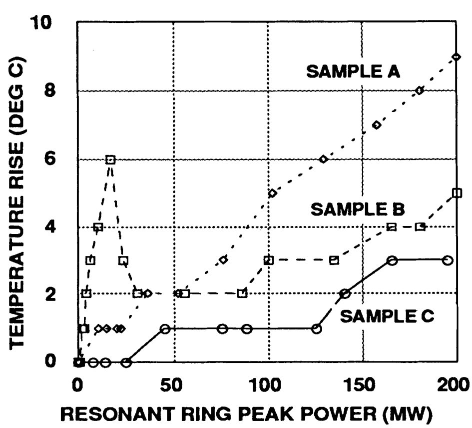

FIGURE 3. Temperature rise of the ceramic window tested in a resonant ring. The coating thickness for the sample A, B, C are 60A, 10A, and 40A respectively.

EXPERIMENTAL RESULT

Output Power Characteristics

FIGURE 4 shows the observed power transfer characteristics of the E3712. The gain is almost the same as predicted by the simulation, but the saturation power efficiency is lower than expected. The cause of the discrepancy may be mismatching of load impedance of the output cavity. The largest output power observed from the first prototype klystron was 72MW under the operating condition listed in TABLE II. FIGURE 5 shows

TABLE II. Operating conditions at the maximum output power

Parameters	Unit	Value
Beam voltage	(kV)	380.0
Beam current	(A)	472.9
Perveance	(10^{-6})	2.02
Repetition rate	(pps)	20
RF pulse duration	(μs)	1.142
Output power	(MW)	72.0
Power gain	(dB)	54.9

experimental data on the output power, gain, and efficiency vs. the beam voltage. It is notable that the output power gradually rises with the higher beam voltage. 100MW output power seems possible when the beam voltage could be raised to 450kV.

Operation Stability

Operation stability was examined under different conditions of beam voltage, beam focusing, and drive power. RF pulse shapes and power transfer

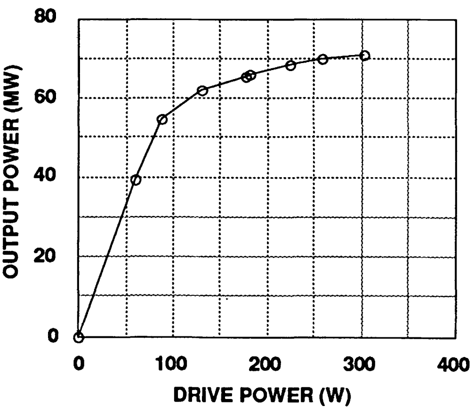

FIGURE 4. Power transfer characteristics under the condition in TABLE II.

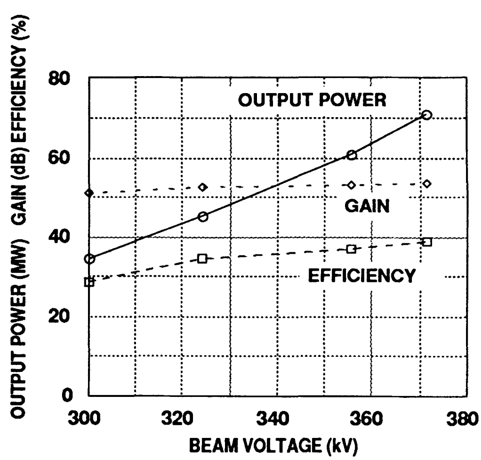

FIGURE 5. Output power, gain, and efficiency at saturation.

characteristics were carefully checked. The observed stability of E3712 was excellent. The output power pulse was very stable under any different beam conditions and at any drive power level. The power transfer characteristics was continuous and smooth. No evidence of instabilities could be observed throughout the experiment.

Output Window

Light emission from the output windows was observed through viewing ports furnished at the power combiner. Very weak bluish light emission was observed at output power of several MW. That seemed a light emission originated from the adsorbed gas molecules on the ceramic surface. Light emission was hardly observed when the output power exceeded 30MW. The TiN coating applied to the windows worked quite well to suppress the multipactoring phenomena.

Trouble of the Electron Gun

All the experiments went quite well, before the electron gun ceramics suffered a pin-holes and the klystron vacuum got poor. It was found by the inspection after the experiment, the oil level of the high voltage insulation tank was dangerously low, and the pin-hole of the ceramics is located just at the oil to air surface. The target beam voltage of 450kV could be applied to the klystron if proper oil level was maintained.

CONCLUSION

An S-band 100MW pulse klystron was built and tested. The output power was getting the higher as the higher beam voltage was applied. The maximum output power achieved was 72MW that exceeds the 67MW output power of SLAC 5045 klystron. 100MW output power could be achieved with the present klystron design. The operating performance was very promising, no instabilities could be observed. The first prototype klystron is now autopsied and the second prototype klystron is now ready for test.

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